

University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

Publications, Agencies and Staff of the U.S.
Department of Commerce

U.S. Department of Commerce

2012

The Global Drought Monitor Portal: The Foundation for a Global Drought Information System

Richard R. Heim Jr.

NOAA/National Climatic Data Center, richard.heim@noaa.gov

Michael J. Brewer

NOAA/National Climatic Data Center, michael.j.brewer@noaa.gov

Follow this and additional works at: <http://digitalcommons.unl.edu/usdeptcommercepub>

Heim, Richard R. Jr. and Brewer, Michael J., "The Global Drought Monitor Portal: The Foundation for a Global Drought Information System" (2012). *Publications, Agencies and Staff of the U.S. Department of Commerce*. 512.
<http://digitalcommons.unl.edu/usdeptcommercepub/512>

This Article is brought to you for free and open access by the U.S. Department of Commerce at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Publications, Agencies and Staff of the U.S. Department of Commerce by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.



Copyright © 2012, Paper 16-015; 8424 words, 18 Figures, 0 Animations, 3 Tables.
<http://EarthInteractions.org>

The Global Drought Monitor Portal: The Foundation for a Global Drought Information System

Richard R. Heim Jr.* and Michael J. Brewer

Climate Monitoring Branch, Climate Services and Monitoring Division, NOAA/National
Climatic Data Center, Asheville, North Carolina

Received 2 February 2012; accepted 18 August 2012

ABSTRACT: The international scientific community has long recognized the need for coordinated drought monitoring and response, but many factors have prevented progress in the development of a Global Drought Early Warning System (GDEWS): some of which involve administrative issues (coordinated international action and policy) while others involve scientific, technological, and logistical issues. The creation of the National Integrated Drought Information System (NIDIS) Portal within the United States provided an opportunity to take the first steps toward building the informational foundation for a GDEWS: that is, a Global Drought Information System (GDIS). At a series of workshops sponsored by the World Meteorological Organization (WMO) and Group on Earth Observations (GEO) held in Asheville, North Carolina, in April 2010, it was recommended that a modular approach be taken in the creation of a GDIS and that the NIDIS Portal serve as the foundation for the GDIS structure. Once a NIDIS-based Global Drought Monitor (GDM) Portal (GDMP) established an international drought clearinghouse, the various components of a GDIS (drought monitoring, forecasting, impacts, history, research, and education) and later a GDEWS (drought relief, recovery, and planning) could be constructed atop it. The NIDIS Portal is a web-based information system

* Corresponding author address: Richard R. Heim Jr., Climate Monitoring Branch, Climate Services and Monitoring Division, NOAA/National Climatic Data Center, 151 Patton Avenue, Asheville, NC 28801-5001.

E-mail address: richard.heim@noaa.gov

created to address drought services and early warning in the United States, including drought monitoring, forecasting, impacts, mitigation, research, and education. This portal utilizes Open Geospatial Consortium (OGC) web mapping services (WMS) to incorporate continental drought monitors into the GDMP. As of early 2012, the GDM has incorporated continental drought information for North America (North American Drought Monitor), Europe (European Drought Observatory), and Africa (African Drought Monitor developed by Princeton University); interest has been expressed by groups representing Australia and South America; and coordination with appropriate parties in Asia is also expected. Because of the range of climates across the world and the diverse nature of drought and the sectors it impacts, the construction and functioning of each continental drought monitor needs to be appropriate for the continent in question. The GDMP includes a suite of global drought indicators identified by experts and adopted by the WMO as the necessary measures to examine drought from a meteorological standpoint; these global drought indicators provide a base to assist the global integration and interpretation of the continental drought monitors. The GDMP has been included in recent updates to the GEO Work Plan and has benefited from substantial coordination with WMO on both their Global Framework for Climate Services and the National Drought Policy efforts. The GDMP is recognized as having the potential to be a major contributor to both of these activities.

KEYWORDS: Global; Drought; Monitoring

1. Introduction

Drought has had a significant impact on civilization throughout history, but it is one of the most difficult phenomena to measure and even to define. Numerous drought indices and indicators have been developed in the last two centuries, based on the sector and location affected, the particular application, and the availability of data, among other factors. Drought can take multiple forms, including meteorological drought (lack of precipitation), agricultural (or soil moisture) drought, and hydrological drought (runoff or streamflow) (Heim 2002; Zwiers et al. 2011). The complexity of drought often results in a definition that is couched in general terms, such as a marked deficiency of precipitation that results in a water shortage or hydrological imbalance that affects some activity or group (WMO 1992; AMS 1997). It is best represented by indicators that quantitatively appraise the total environmental moisture status or imbalance between water supply and water demand (Heim 2002). Civilization has struggled to develop early warning and other response systems to address the drought problem, but the diversity of climates, range of sectors impacted, and inconsistency in available resources and data make even drought assessment—on a continental scale, let alone on a global scale—difficult (Sivakumar 2009). This paper discusses the development of the Global Drought Monitor and Global Drought Monitor Portal, a coordinated effort to tackle the drought monitoring problem on a continental and global scale (see Table 1 for the distinction between the Global Drought Monitor, Global Drought Monitor Portal, Global Drought Information System, and Global Drought Early Warning System).

Every continent has regions and climates that are susceptible to drought, including semiarid areas that are especially vulnerable to drought. In North America and Europe today, drought impacts are largely economic (Markandya 2010).

Table 1. Acronyms used in this paper.

Acronym	Description
GDM	Global Drought Monitor: a product depicting drought occurring on a global basis, constructed from drought depictions prepared by the nations of each continent.
GDMP	Global Drought Monitor Portal: a web portal, utilizing Open Geospatial Consortium web mapping services, which provides the IT infrastructure housing the GDM and is constructed in such a way that it could be the IT home for a Global Drought Information System.
GDIS	Global Drought Information System: an IT-based system (housed within the GDMP) into which global drought information from originating countries is sent and made available in a coordinated and consistent manner. The GDIS addresses mainly scientific aspects of drought and includes informational components covering drought monitoring (the GDM), drought forecasting, drought impacts, history of drought episodes by continent, drought research, and drought education.
GDEWS	Global Drought Early Warning System: an IT and administrative system for coordinated international action and policy concerning drought issues on a global scale. The GDEWS includes an informational component (the GDIS), action components (for drought relief, recovery, and planning), and a policy component.

However, in most of the rest of the world, drought-induced crop failure and famine can create severe hardship. In 1992, an International Conference on Climate, Sustainability and Development in Semiarid Regions (ICID-I) focused the world's attention on the plight of drylands peoples and was influential in the negotiation of the United Nations (UN) Convention to Combat Desertification (UNCCD). With 193 country parties to the convention, the UNCCD is a global mechanism to combat desertification and mitigate the effects of drought through national action programs that incorporate long-term strategies supported by international cooperation and partnership arrangements. Since ICID-I, increasing attention has been paid to how a changing climate may affect the frequency and intensity of drought.

In a globally warmed world, the warming can intensify hydrological droughts and alter runoff timing from snowmelt, affecting water management decisions (Barnett et al. 2008; Cayan et al. 2010), and drought-affected areas will likely increase in extent and the vulnerability of semiarid regions to drought will also likely increase (Adger et al. 2007). As noted by the Intergovernmental Panel on Climate Change (Adger et al. 2007), some countries have made efforts to adapt to the recent and projected changing climate conditions, particularly through conservation of key ecosystems, early warning systems, risk management in agriculture, strategies for flood drought and coastal management, and disease surveillance systems. Local, national, and regional collaborative drought monitoring efforts have been summarized at several venues, including gatherings sponsored by the World Meteorological Organization (WMO) of experts in Lisbon, Portugal, in 2000 (Wilhite et al. 2000); Lincoln, Nebraska, in 2009 (Hayes et al. 2011); and Washington, D.C., in 2011 (Sivakumar et al. 2011b) and at the Second International Conference on Climate, Sustainability and Development in Semiarid Regions (ICID+18) held in Fortaleza, Brazil, in 2010 (see online at <http://icid18.org/?locale=en&m=scheduling&a=view&right=no>). However, the effectiveness of these collaborative drought monitoring efforts is outweighed by lack of basic information, observation, and monitoring systems; lack of capacity building and appropriate political, institutional, and technological frameworks; low income; and settlements in vulnerable areas, among others (Adger et al. 2007). These shortcomings

have inhibited the development of an integrated Global Drought Early Warning System (GDEWS) (Wilhite 2005).

In addition, for many decades attempts to manage drought and its impacts have been made through a reactive crisis management approach. This approach has proven to be ineffective, poorly coordinated, and untimely (Wilhite et al. 2005). In the United States, the National Integrated Drought Information System (NIDIS) was established by the NIDIS Act in 2006 as a proactive mechanism for the following:

- developing the leadership and networks to implement an integrated drought monitoring and forecasting system at federal, state, and local levels;
- fostering and supporting a research environment focusing on risk assessment, forecasting, and management;
- creating an early warning system for drought to provide accurate, timely, and integrated information;
- developing interactive systems, such as the web portal, as part of the early warning system; and
- providing a framework for public awareness and education about droughts (NPIT 2007).

It has been only in recent years that steps have been taken to construct a functional framework that could integrate the existing regional drought monitoring efforts and build the components of a GDEWS. The Global Drought Monitor Portal described in this paper serves as an informational foundation upon which a GDEWS can be built.

2. Laying the groundwork for a Global Drought Early Warning System

Several organizational meetings have been held in the last few years to frame the issue and identify the steps to make a GDEWS a reality. Much of this work has been done by or with the support or sponsorship of the WMO and the Group on Earth Observations (GEO).

2.1. Expressing the need for a GDEWS

At the Fourth GEO Plenary Session and Ministerial Summit held in Cape Town, South Africa, in November 2007, representatives from more than 70 nations reaffirmed their commitment to working together, at both the political and technical levels, to improve the interoperability of observation, prediction, and information systems as part of the Global Earth Observation System of Systems (GEOSS). Recognizing the growing problem of drought and its impact on long-term sustainability of the earth's water resources, the event concluded with a U.S. proposal that technical representatives from participating countries build upon existing programs to work toward establishing a GDEWS within the coming decade to provide a system of systems for data and information sharing, communication, and capacity building to take on the growing worldwide threat of drought and regular drought warning assessments issued as frequently as possible with increased frequency during a crisis.

2.2. Standard global drought indicators

Several workshops were held by the WMO to determine if agreement could be reached on drought indices that could be applied globally to monitor meteorological, agricultural, and hydrological droughts. The standardized precipitation index (SPI) was recommended by the WMO Congress to characterize meteorological droughts based on the “Lincoln Declaration on Drought Indices” resulting from the WMO Interregional Workshop on Indices and Early Warning Systems for Drought held in Lincoln, Nebraska, in December 2009 (Hayes et al. 2011). The workshop participants noted that the SPI should be used by all national meteorological and hydrological services as the standard index available worldwide in addition to unique local indices and indicators being used nationally within each country.

The WMO/UN Strategy for International Disaster Reduction (UNISDR) Expert Meeting on Agricultural Drought Indices, held in June 2010 in Murcia, Spain, to identify standard indices to monitor agricultural drought, did not reach consensus on a single drought index to recommend for agricultural drought. However, key conclusions and recommendations included the following: (i) countries around the world should move beyond the use of just rainfall data in the computation of indices for the description of agricultural droughts and their impacts; (ii) a composite index, such as the U.S. Drought Monitor (Svoboda et al. 2002), should be considered; (iii) there is a strong need for establishment of soil moisture monitoring networks where they do not currently exist; and (iv) a survey should be conducted to compile and assess the resources (data networks, deliverables, and indices used/calculated and disseminated), capacities, user needs, and future needs of national meteorological and hydrological services in building common frameworks for national agricultural drought early warning systems (Sivakumar et al. 2011a).

The WMO/UNISDR Expert Meeting on Hydrological Drought Indices was held in September 2011 in Geneva, Switzerland. As with the agricultural drought indices workshop, this meeting did not result in a consensus recommendation on an index to be used for worldwide monitoring of hydrological drought. This is due to the complex nature of hydrological drought, the time lag between the occurrence of meteorological drought and the occurrence of hydrological impacts, the dependence of hydrological drought on basin-specific characteristics, and how hydrological drought and associated indices are influenced by watershed management practices and changes in land use. However, several hydrological drought indices that could be considered include reservoir level, low streamflow index, a composite hydro index, and precipitation-based indices such as the SPI or percent of normal precipitation (Stefanski 2011). Efforts to reach a consensus continue.

2.3. The April 2010 Global Drought Assessment Workshop: Creating the foundation for a component-based GDEWS

In April 2010, a Global Drought Assessment Workshop was held in Asheville, North Carolina, to move the coordinated global drought monitoring efforts of the WMO and GEO forward. [This workshop was part of a series of drought workshops held in Asheville during the week of 20–23 April 2010. The other workshops included the biennial North American Drought Monitor (NADM) Forum and the

U.S.–Canadian GEO Bilateral Technical Workshop (Heim and Brewer 2010; Brewer and Heim 2011a).] It was quickly recognized at the Asheville global workshop that no single nation or organization can afford to tackle all of the hurdles involved in creating a GDEWS in its entirety. However, it was believed that small pieces of a GDEWS could be assembled in an incremental way. If an international drought clearinghouse and web services infrastructure could be established—that is, if a global web portal “foundation” could be laid—then it might be easier to construct the GDEWS “building” atop it.

The NIDIS drought portal managers noted that the NIDIS portal was developed to support drought monitoring, forecasting, research, and impacts assessment in the United States, and new web mapping services had been developed to distribute the information that Canada, Mexico, and the United States integrate to aid in the production of the NADM. These new NADM web services were being housed in the U.S. Drought Portal in a North American–specific site. These new tools would allow additional accuracy in the development of the NADM by allowing the overlay of information as well as increase the utility of the data by providing it in more accessible and useful formats. With minimal additional effort, a prototype Global Drought Monitor Portal (GDMP) could be developed as an outgrowth of the NIDIS portal modifications. The workshop recommended and the portal managers agreed to develop a prototype GDMP within the NIDIS portal environment to serve as a clearinghouse for international drought information. Once the digital infrastructure was created, the GDMP could be populated with drought information from around the world and serve as the foundation for a Global Drought Information System (GDIS) (Heim and Brewer 2010; Brewer and Heim 2011a). Additional policy and actionable components (drought response and mitigation) could be added later to the GDIS in order to make a complete GDEWS.

Building upon the recommendations of the earlier Interregional Workshop on Indices and Early Warning Systems for Drought, the Global Drought Assessment Workshop recommended that the GDMP provide a number of different depictions of drought on the global scale, developed using data from WMO World Data Centers and including such drought indices as the SPI at various time scales as well as satellite-based indices providing global coverage. The workshop also suggested that, in addition to the SPI, drought impacts information should be included globally, if available, and that categories of indices be identified instead of specific indices (e.g., some evapotranspiration-based index, some soil moisture index, and modeled indices as well as satellite-based vegetation indices). The remotely sensed data should be used in conjunction with in situ data, especially in parts of the world where in situ data are difficult to obtain. The GDMP would house a Global Drought Monitor (GDM) whose global drought depiction would be constructed from continental drought depictions prepared and contributed by the nations of each continent. The experimental GDMP was demonstrated at the Seventh GEO Plenary Session and Ministerial Summit held in Beijing, China, in November 2010.

2.4. The global drought forecasting component

A World Climate Research Programme (WCRP) Workshop on Drought Predictability and Prediction in a Changing Climate, held in Barcelona, Spain, in March

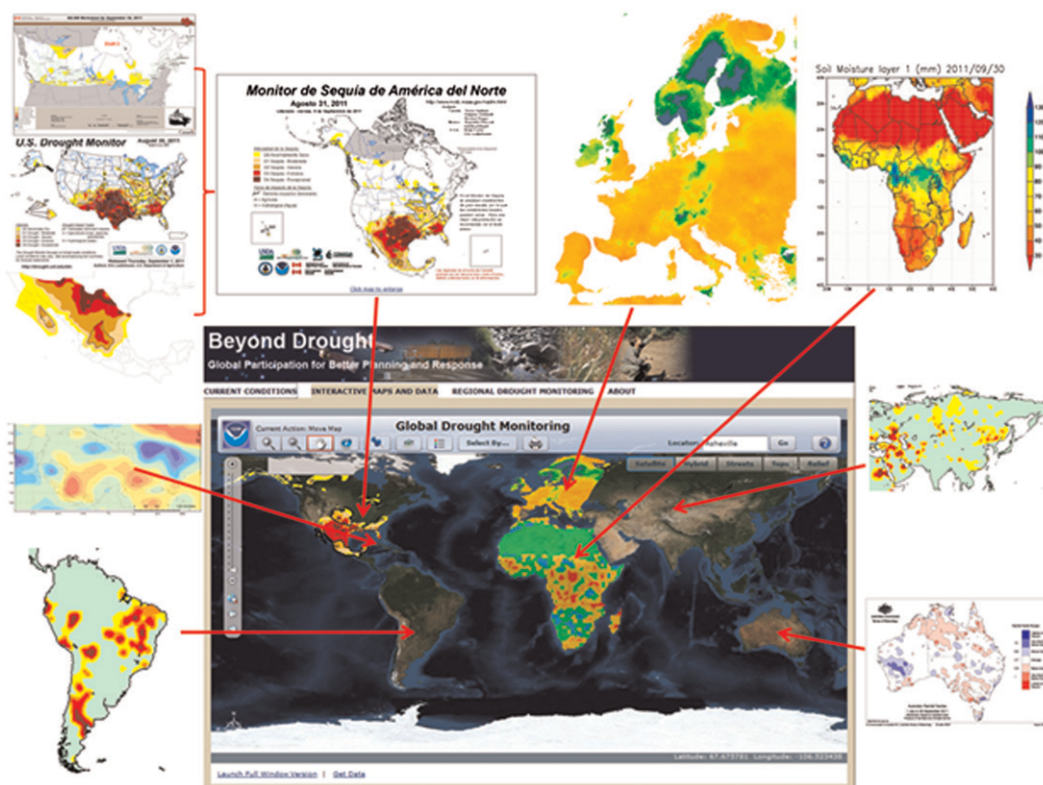


Figure 1. Conceptual design for the GDM component of the GDIS. Continental and regional drought monitors, created by partners on the respective continents, are integrated into the GDM for a truly global picture of drought monitoring.

2011, sought to advance regional drought prediction capabilities for variables and scales most relevant to user needs on subseasonal to centennial time scales. The action plan developed by the workshop had applications to a GDIS, with the key recommendations including the following: (i) develop a drought catalogue that summarizes our current understanding of the causes of drought worldwide, to include the important time scales (e.g., subseasonal, seasonal, decadal, centennial) and mechanisms [e.g., ENSO, Pacific decadal oscillation (PDO), land feedbacks, global warming] for each region; (ii) define case studies and carry out a coordinated analysis of the mechanisms, predictability, and prediction skill, which could evolve into a regular annual assessment of worldwide drought; and (iii) actively contribute to the development and improvement of drought early warning systems (DEWS) by taking advantage of current capabilities in drought prediction and monitoring (WCRP 2011). A follow-up workshop on further developing global drought forecasting capabilities within the context of a GDIS was held in April 2012 in Frascati, Italy. In addition to the recommendation that the GDMP serve as the backbone for a GDIS, this GDIS Workshop addressed details for developing the drought forecasting and drought catalog components, which will be incorporated into the GDIS.

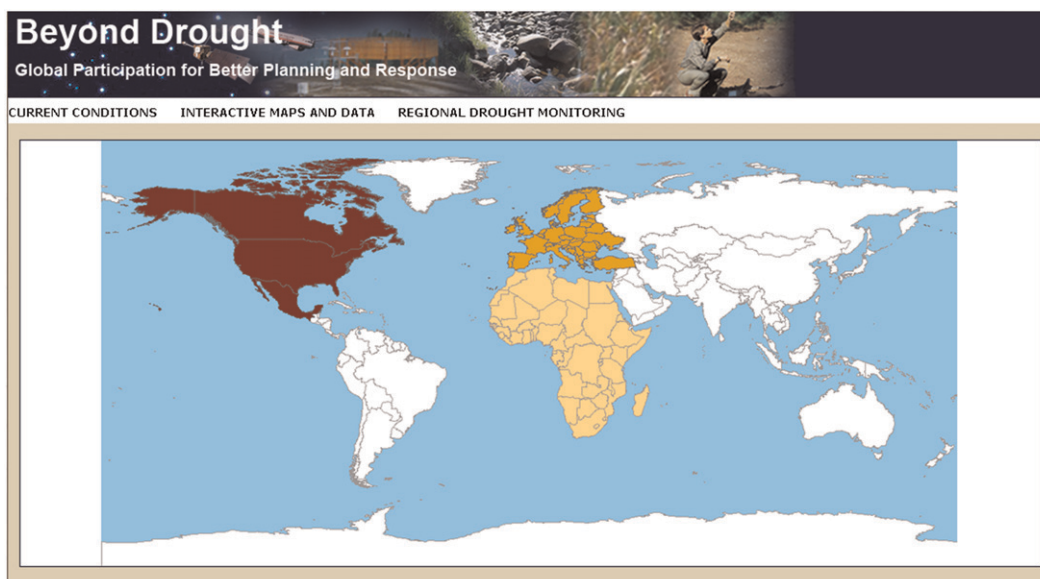


Figure 2. North America (North American Drought Monitor), Europe (Europe Drought Observatory), and Africa (Africa Drought Monitor) are represented on the GDM as of early 2012.

2.5. The drought policy component

Two workshops were held by the WMO in 2011 to address the development of the policy needed for a GDEWS: the first, *Toward a Compendium on National Drought Policy*, was held in July in Washington, D.C., and the second, the *International Symposium on Integrated Drought Information Systems*, was held in November in Casablanca, Morocco. Recognizing that each country is unique in its vulnerability and institutional capacity to prepare for and respond to drought and that the national drought policy for any given country will depend very much on the local circumstances and priorities, the July workshop proposed several elements on national drought policy in a compendium form so that countries could adopt those elements that will be appropriate to their local circumstances and national priorities. The 32 elements were grouped under three main categories: (i) drought monitoring and early warning systems, (ii) vulnerability assessment and impacts, and (iii) emergency relief and response (Sivakumar et al. 2011b). The November meeting focused on further developing these pieces at the national level so they could contribute to a successful GDIS.

3. The Global Drought Monitor

It has long been recognized that a global-scale drought monitoring, mitigation, and response system would provide important benefits to all nations affected by drought, especially to those peoples in semiarid regions. National drought early warning systems have been created in many areas, including the United States (U.S. Drought Monitor and NIDIS), Australia, Brazil, Canada, China, Hungary,

Table 2. Characteristics for the creation of continental Drought Monitors for North America (NADM model), Europe (EDO model), and Africa (ADM model).

	NADM model	EDO model	ADM model
Drought experts	In-house expertise for monitoring, forecasting, impacts, research, planning, and education	In-house expertise for continental monitoring, forecasting, impacts, research, planning, and education; combined with regional, national, and local expertise	External expertise for monitoring and forecasting, coupled with in-house expertise for impacts, research, planning, and education
National climate observing network	Extensive data networks and near-real-time daily observations from all three countries; supplemented by continental satellite observations and model data	Extensive data networks providing near-real-time daily observations (>30 countries); supplemented by satellite observations and modeled data	Extensive data networks and near-real-time daily observations for some nations (more satellite observations than in situ observations for most regions)
National drought assessments	National Drought Monitors in each country already routinely produced timely (monthly or more frequently) and merged into continental drought monitor	Continental assessment done at JRC, complemented by regional, national and local (e.g., river basin) assessments, where available; the latter are accessible through EDO	No currently existing National Drought Monitor assessments (National Drought Monitor assessments do not go into the continental assessment)
International data exchange	Station data exchanged for creation of regional or continental standardized indicators	Station data from GTS and other sources and forecasting data from ECMWF; common drought indices for multiscale assessment and mutual exchange of knowledge; local indicators accessible through EDO	Station data from GTS and CLIMAT transmissions are used for real-time data; historical data are from GHCN and similar compilations
International collaboration	National experts collaborate to create regional or continental drought monitor	Continental monitoring coordinated by EDO (EC Joint Research Centre); national expert network to support development	Nations on the continent request experts from outside to create regional or continental drought monitor that are run in house
IT infrastructure	ArcGIS, web, and e-mail	Web, interoperable OGC-compliant map servers, ArcGIS, and Oracle database	Web, GIS, Google Maps, and e-mail

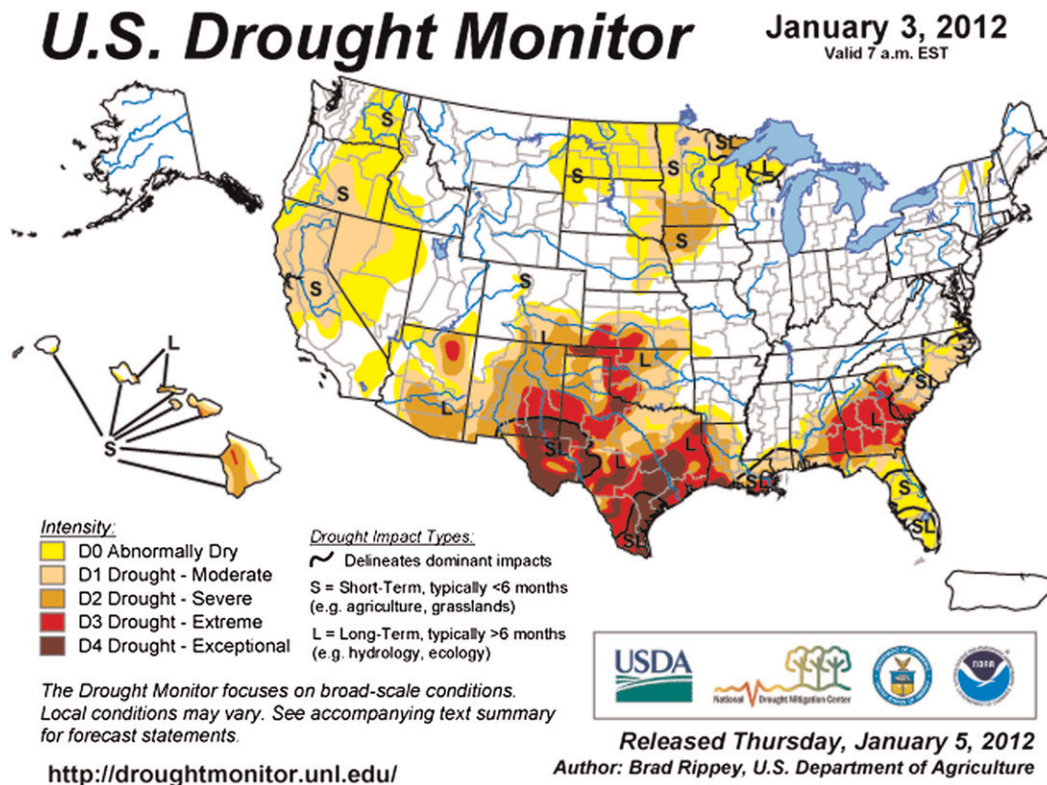


Figure 3. The USDM for 3 Jan 2012.

India, Mexico, Nigeria, the Philippines, Romania, and South Africa. Regional drought monitoring centers or activities have been established in North America (North American Drought Monitor); Europe (European Drought Observatory through the European Commission Joint Research Center); southeastern Europe; eastern, western, and southern Africa; North Africa; west and central Asia; Southeast Asia (Southeast Asia Drought Monitor developed by the International Water Management Institute); and the Caribbean, and international groups [e.g., the UN Food and Agriculture Organization (FAO) Global Information and Early Warning System on Food and Agriculture (GIEWS), the World Food Programme (WFP) Humanitarian Early Warning Service (HEWS), the UNISDR, and the Famine Early Warning System (FEWS Net)] provide information on major droughts occurring globally in support of famine relief (Wilhite et al. 2000; Hayes et al. 2011; Sivakumar et al. 2011b). Many of these efforts have come to fruition through work associated with the UNCCD. However, major parts of the world that face recurring severe droughts still do not have comprehensive information and early warning systems in place (Sivakumar et al. 2011b). The creation and maintenance of national and regional DEWSs in these other areas, as well as the creation and maintenance of a GDEWS, are inhibited by many hurdles, including inadequate data networks (station density and data quality), inadequate data sharing (both between government agencies and due to the high cost of data), data and information products that are too complex for use by

Table 3. The U.S. Drought Monitor classification and ranking percentile scheme.

Category	Description	Ranking percentile
D0	Abnormally dry	30
D1	Moderate drought	20
D2	Severe drought	10
D3	Extreme drought	5
D4	Exceptional drought	2

decision makers, unreliable seasonal forecasts, inadequate indices for detecting the early onset and end of drought, the lack of integrated physical and socioeconomic indicators for drought, the lack of impact assessment methodology, data and information frequently unavailable on an operational real-time basis, and inadequate comprehensive global historical database and assessment products (Wilhite et al. 2000; Wilhite and Buchanan-Smith 2005; Adger et al. 2007). An additional hurdle is the lack of resources to address these issues. While the GDMP, by itself, is not able to solve these basic hurdles, it provides a mechanism through which coordinated solutions can be sought by leveraging existing technology and building upon the lessons learned from establishing the NIDIS (Brewer and Heim 2011b).

North American Drought Monitor

December 31, 2011

Released: January 12, 2012

<http://www.ncdc.noaa.gov/nadm.html>

Analysts:

Canada - Trevor Hadwen
Richard Rieger
Mexico - Reynaldo Pascual
Adelina Albanil
U.S.A. - Brad Rippey
Brad Pugh*

(* Responsible for collecting analysts' input & assembling the NA-DM map)

Intensity:

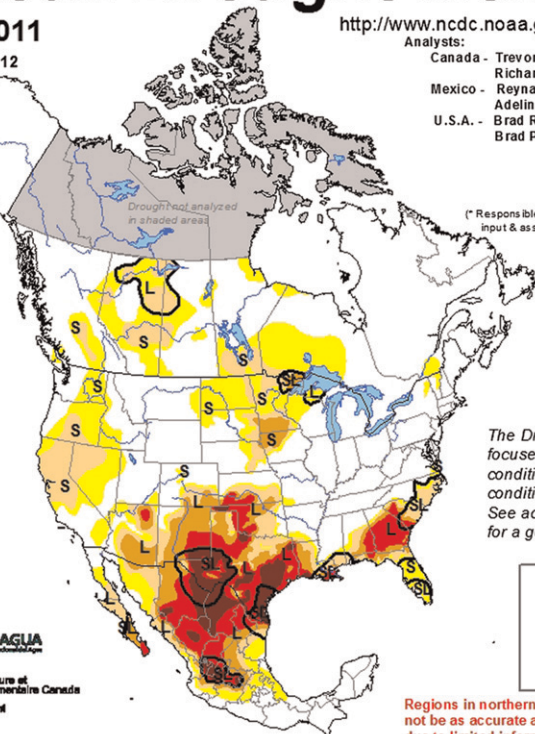
- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:

~ Delineates dominant impacts

S = Short-Term, typically < 6 months
(e.g. agriculture, grasslands)

L = Long-Term, typically > 6 months
(e.g. hydrology, ecology)



The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text for a general summary.

Regions in northern Canada may not be as accurate as other regions due to limited information.

Figure 4. The NADM for the end of December 2011.

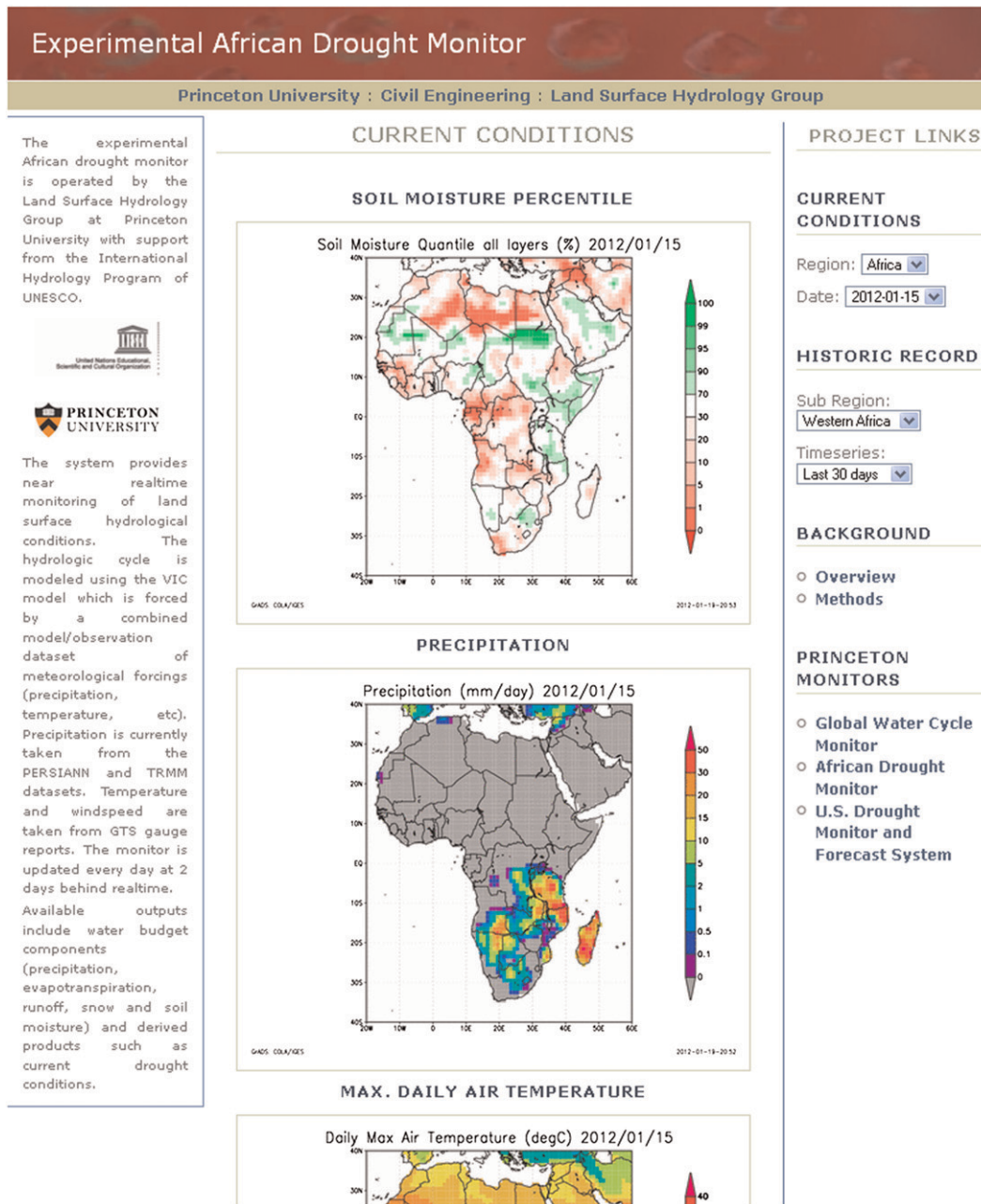


Figure 5. Selected maps from the African Drought Monitor for 15 Jan 2012.

3.1. Global drought monitoring by integrating continental drought monitors

The GDM, constructed atop the GDMP, can integrate the existing continental and regional drought monitoring map products and activities to function as a truly global drought monitoring mechanism (Figure 1). This is a collaborative process

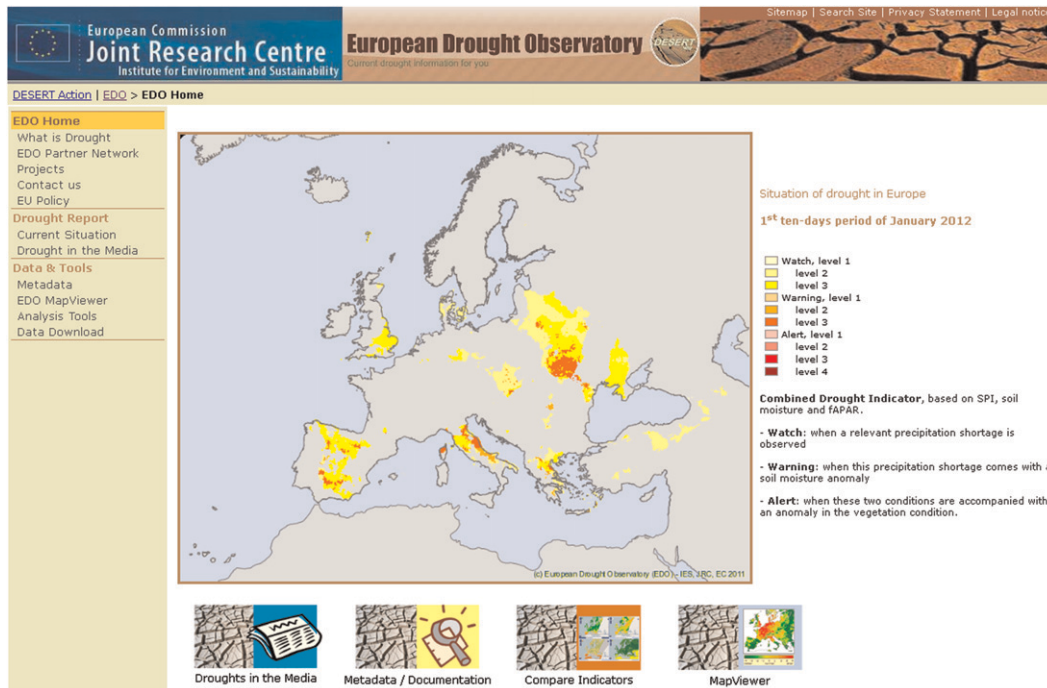


Figure 6. EDO drought depiction for Europe for the first 10 days of January 2012.

whereby each regional or continental drought monitor (CDM) is prepared by the participating nations of that region or continent and integrated into the web-based GDM global map. This idea builds upon previous work by the National Drought Mitigation Center and Dr. Don Wilhite, in the early 2000s, that pointed to the need for a global drought preparedness network built through regional and global partnerships. Indeed, this effort has resulted in the establishment of numerous regional drought monitoring networks (Wilhite 2002; Lawrimore et al. 2002) that contribute data and analysis to the current integration effort.

Each CDM is prepared using a model uniquely adapted to the requirements and resources of the respective region or continent. As of early 2012, CDM map products for North America, Europe, and Africa were integrated and displayed as part of the GDM (Figure 2); interest has been expressed by groups representing Australia and South America; and coordination with appropriate parties in Asia is also expected. Leads in each region provide access to the regional drought depiction and coordinate with those within the region on drought monitoring. The NADM is the assessment for North America, the European Drought Observatory (EDO) provides the assessment for Europe, and the African Drought Monitor (ADM) developed by Princeton University is used for Africa.

Existing CDMs have largely built upon existing coordination activities within a region that have led to the development of drought information at a continental scale. It is recognized that continuing to add additional regions, as well as improving existing regions, will require extensive coordination and buy in from local and national partners who can contribute and take advantage of the information

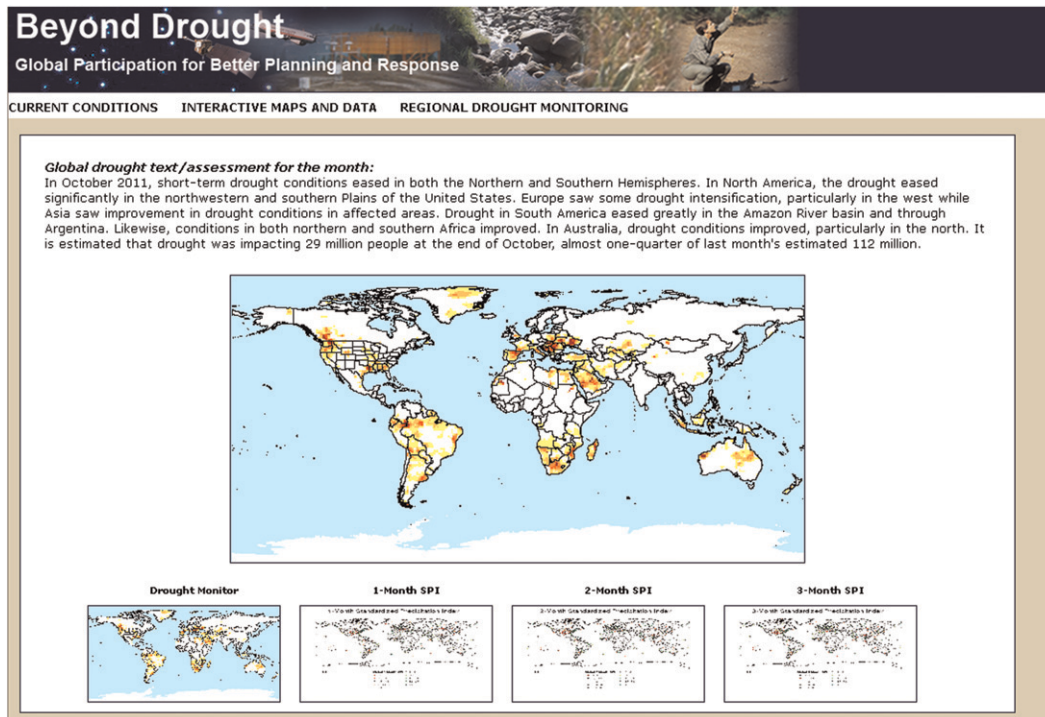


Figure 7. The Global Drought Monitor Portal global drought assessment and limited number of global products.

available through the GDMP. It is envisioned that this coordination will look different in different locations around the world, but it is essential to ensure that the most accurate and representative information possible be available through the GDMP. The level of information technology (IT) infrastructure, drought expertise, international collaboration and data exchange, drought assessment capability, and national climate observing systems varies among the continents. Table 2 summarizes these characteristics for the NADM, EDO, and ADM models. Continental or regional drought monitors (DMs) are needed since the NIDIS IT resources could not integrate the dozens of national DMs that are available or will be available in the future. For consistent depiction of drought on a global scale, the integration of CDMs requires the establishment of certain standards among the CDMs for the depiction of drought (e.g., using a drought classification scale similar to the NADM), the creation of CDM shape files in a GIS environment, and the smoothing of CDM drought depictions along continental boundaries.

3.1.1. The U.S. Drought Monitor and North American Drought Monitor

The wide variety of sectors affected by drought, its diverse geographical and temporal distribution, and the demand placed on water supply by human-use systems make it difficult to develop a single definition of drought. The use of a single index will rarely work for all places at all times and for all types of droughts.

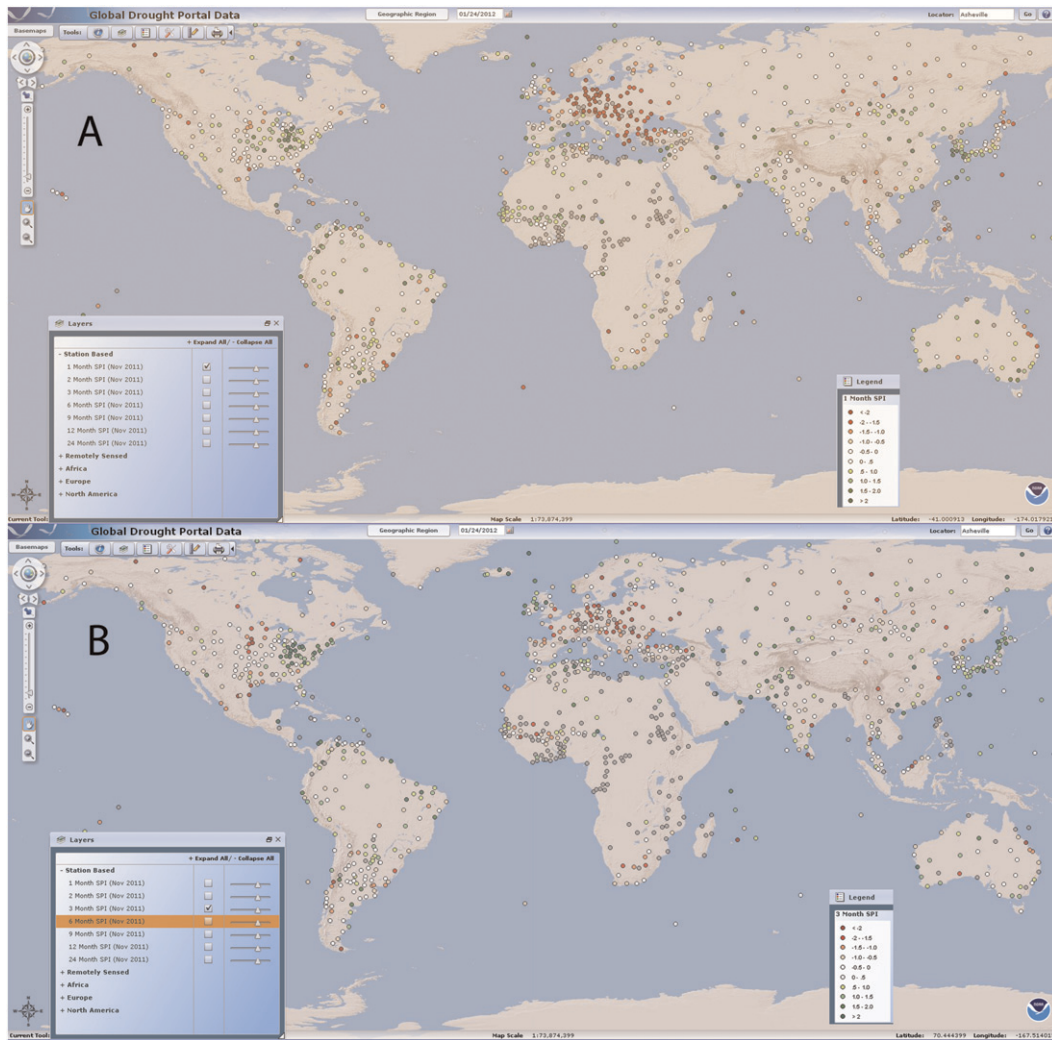


Figure 8. Example of the Global Drought Monitor Portal depicting station data for (a) 1- and (b) 3-month SPI on a relief base map.

As a result, numerous indices have been developed during the last hundred years to measure the intensity, impact, and geographic extent of drought (Heim 2002). At the end of the twentieth century, a new approach to drought monitoring—a composite approach—was developed in which numerous indices and indicators are consolidated into one comprehensive composite index. This is the approach used for the NADM. This composite approach is used in the United States for the U.S. Drought Monitor (USDM) (Svoboda et al. 2002) and for national drought monitoring in Canada (Hadwen 2012) and Mexico (Lobato Sánchez 2012). The NADM, a monthly product that assesses current drought conditions on a continent-wide basis, is produced via collaboration between these three countries.

The USDM (Figure 3) is produced on a weekly basis by examining several in situ and remotely sensed objective drought indices and indicators, as well as

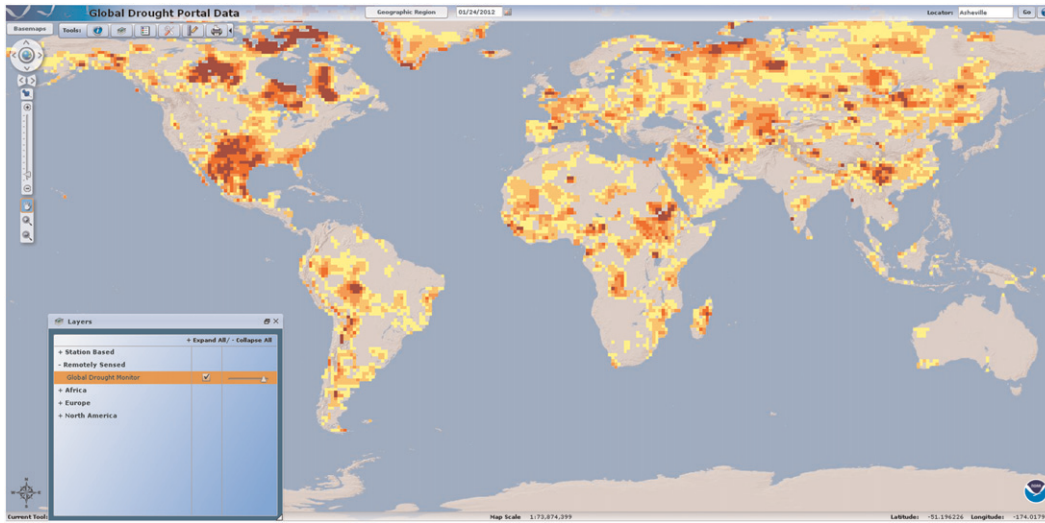


Figure 9. Example of Global Drought Monitor Portal depiction of remotely sensed data expressed in the North American Drought Monitor drought categories, shown on a relief base map.

impacts information and local field reports. The indices and indicators are combined using a simple D0–D4 scheme and a percentile ranking methodology (Table 3) to address both short-term and long-term drought. The key indicators and indices are derived from precipitation, temperature, streamflow, soil moisture, snowpack, and snow water equivalent observations and include the SPI, Palmer drought severity index, and satellite-derived vegetation health indices such as the vegetation drought response index (VegDRI) (Brown et al. 2008). The USDM undergoes a peer-review process each week during its preparation to ensure that the weekly drought depiction represents the best “blended convergence of evidence” (Svoboda et al. 2002; Sivakumar et al. 2011a). Drought monitoring on a monthly basis is done in Canada (Hadwen 2012) and Mexico (Lobato Sánchez 2012) using a similar approach. The USDM may be accessed via the web (at <http://droughtmonitor.unl.edu/>).

The NADM (Figure 4) is prepared on a monthly basis from the monthly drought depictions for Canada and Mexico and from the USDM for the week closest to the end of the month for the United States (Lawrimore et al. 2002; Heim and Brewer 2010; Sivakumar et al. 2011a). The drought depictions in each of the three countries are prepared independently of each other by experts within each country. ArcGIS software is used to prepare the national drought depictions in shape-file format using the standard USDM D0–D4 classification scheme. The lead author, who rotates each month between the three countries, merges the GIS shape files into a continental depiction. Continental drought indicators, computed using the same methodology and calibration periods from data provided by the three countries, are used as guidance to adjust the depictions across the international boundaries where disagreement between the national DMs exists. The continental indicators currently include the SPI, Palmer drought indices, and percent of long-term average precipitation,

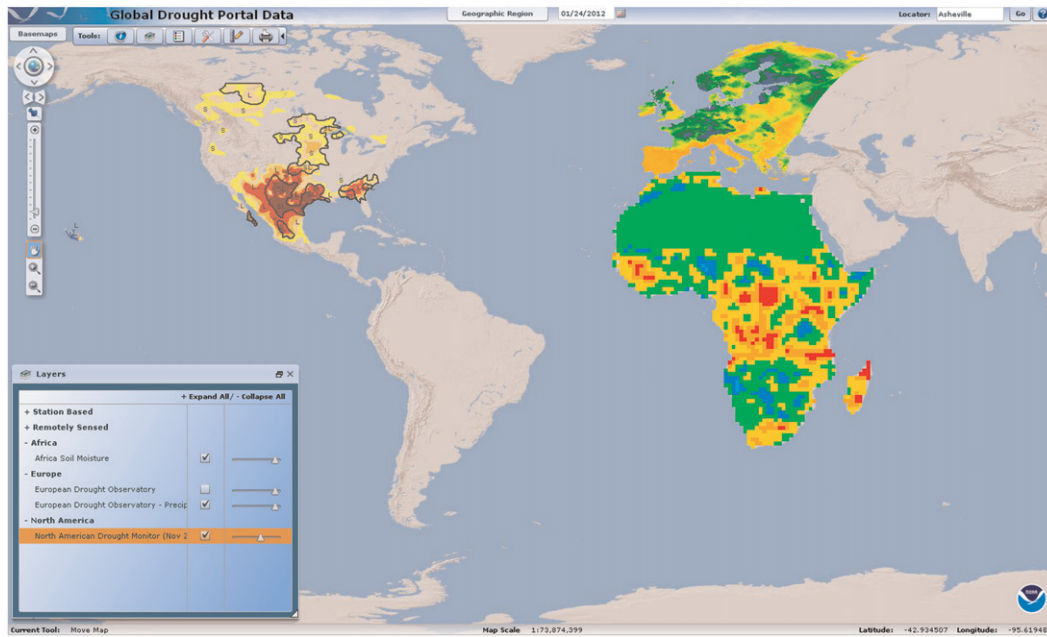


Figure 10. Example of drought depictions from the North American Drought Monitor, European Drought Observatory, and African Drought Monitor integrated into the Global Drought Monitor, shown on a relief base map.

as well as modeled soil moisture from the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center and satellite-derived vegetation health indices. The lead authors are currently provided by NOAA, the U.S. Department of Agriculture, and the National Drought Mitigation Center in the United States; Agriculture and Agri-Food Canada in Canada; and the National Meteorological Service (SMN) in Mexico. The map and associated narrative (national narratives are written within each country and merged by the lead author) are translated into the languages of the three countries, English, French, and Spanish. The NADM may be accessed via the web (at <http://www.ncdc.noaa.gov/temp-and-precip/drought/nadm/>).

The collaborative NADM model works for North America because (i) all three countries have compatible IT infrastructure, create national drought depictions on an operational basis, and produce their national components (national drought depictions) in an agreed-upon D0–D4 GIS format; (ii) extensive data networks and near-real-time daily climate observations exist within each country; and (iii) collaborative agreements are in place for international data exchange and sharing of drought expertise for monitoring, forecasting, and research. The NADM model may not work for other continents where these conditions are not met.

3.1.2. The African Drought Monitor

For continents where the climate observing networks or IT infrastructure vary from country to country, a different CDM model is needed. In Africa, extensive

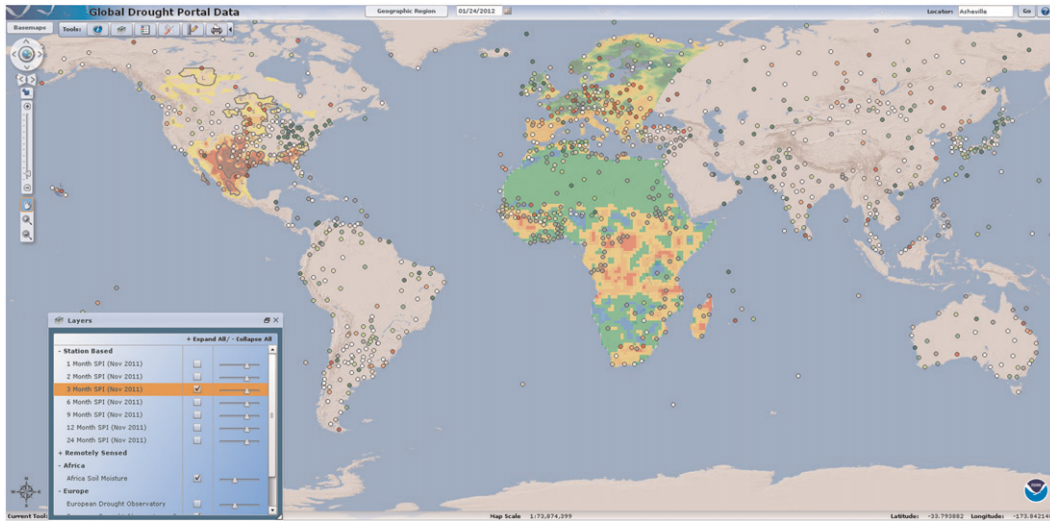


Figure 11. Example of Global Drought Monitor Portal depicting data from multiple layers shown on a relief base map. The layers include the North American Drought Monitor, European Drought Observatory, and African Drought Monitor drought conditions with 3-month SPI station data.

data networks and near-real-time daily observations are available for some nations but not for others, and national drought monitor assessments generally are not made on a routine basis and thus are not available for integration into a CDM. Nations on such continents may need to request expertise from outside for drought monitoring and forecasting, coupled with in-house expertise for impacts, research, planning, and education. This is the case for Africa, where Princeton University developed the African Drought Monitor (Figure 5), which is run in house and being transitioned from Princeton to the Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Centre (ICPAC) in Kenya (Sheffield et al. 2008). The ADM, based on soil moisture, is produced for the entire continent using a consistent methodology, where station data from GTS and CLIMAT (WMO code for reporting monthly climatological data) transmissions are used for real-time observations and historical data are from the Global Historical Climatology Network (GHCN) and similar compilations (J. Sheffield 2012, personal communication). Currently, the ADM may be accessed online (at http://hydrology.princeton.edu/~nchaney/Africa_Drought_Monitor_Webpage/GMinterface.php).

3.1.3. Drought monitoring in Europe: The European Drought Observatory model

Europe provides a third example for monitoring drought on a continental basis. Each country has extensive data networks providing near-real-time daily observations, supplemented by satellite observations and modeled data. Through the European Commission, the political infrastructure exists for the creation of international agreements that govern joint research, information sharing, and provision of services, thus enabling the European Commission (EC) Joint Research

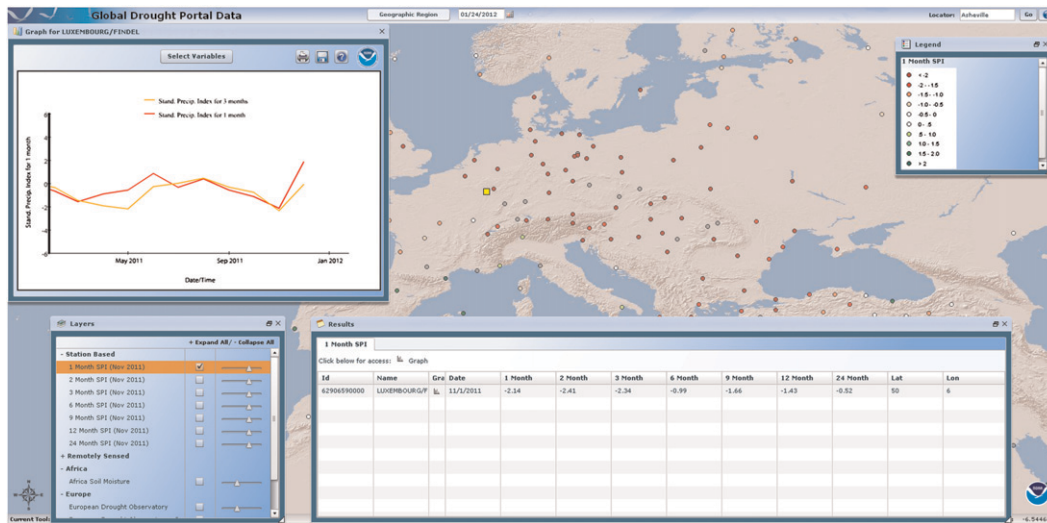


Figure 12. Example of the Global Drought Monitor Portal allowing the user to zoom in to display data for individual locations. Depicted here is SPI data for Findel, Luxembourg, with the station's 1- and 3-month SPI plotted in the time-series box.

Centre (JRC) to establish the EDO as a tool for assessing, monitoring, and forecasting droughts on a continental scale in Europe (Rossi and Niemeyer 2010; Vogt 2010). With in-house expertise for continental monitoring, forecasting, impacts, research, planning, and education, the EDO conducts continental drought assessment (Figure 6), complemented by regional, national, and local expertise and assessments, where available. The station data come from the GTS and other sources, forecasting data are available from the European Centre for Medium-Range Weather Forecasts (ECMWF), and common drought indices are computed by EDO for multiscale assessment and the mutual exchange of knowledge. Local drought indicators are also accessible through the EDO (J. Vogt 2012, personal communication). The EDO may be accessed online (at <http://edo.jrc.ec.europa.eu/php/index.php?id=1>). Current information provided to the GDMP from EDO is precipitation and SPI data.

3.1.4. U.S.-affiliated Pacific islands drought monitoring

Coordinated drought monitoring activities in the Pacific Islands are currently being developed. Through the work of the Pacific Islands Climate Information System and the National Climatic Data Center, drought monitoring and coordination activities have increased, by leveraging existing communications channels, to include a monthly discussion of drought across the basin and to get consensus across the Pacific Islands on the state of drought. This activity is geared toward establishing more frequent and objective analyses of drought across the Pacific by encouraging island nations to provide more timely data for analysis, with the goal to create daily to weekly precipitation assessments in support of the drought monitoring activity. The result has been a new section of the National Climatic

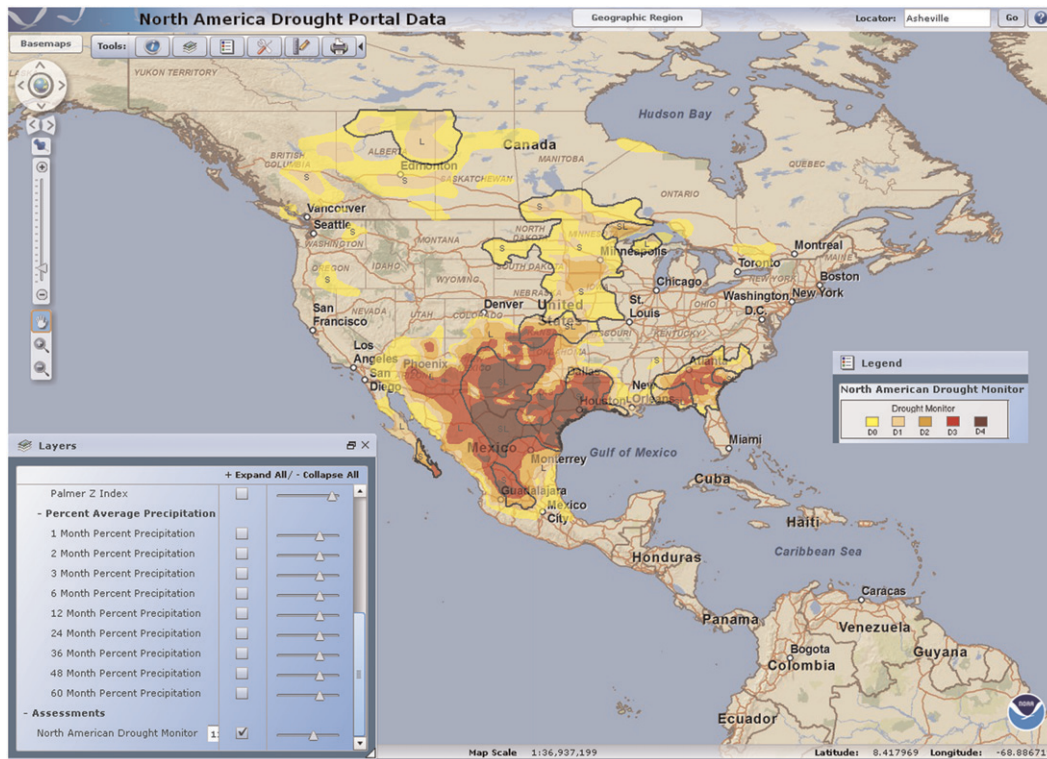


Figure 13. Example of North America drought depiction provided by the North American Drought Monitor, depicted on the Global Drought Monitor Portal using a streets base map.

Data Center's U.S. State of the Climate monthly report that highlights and reports on drought across the Pacific Islands. An example can be seen online (at <http://www.ncdc.noaa.gov/sotc/drought/2012/5#det-reg-pacis>).

3.2. The Global Drought Monitor Portal: Structure and functionality

The GDMP currently includes four sections. The first is an abbreviated monthly drought assessment along with a series of global drought indicator products, including the SPI (Figure 7). Products used to populate this section are peer evaluated by the participating regional partners for their applicability, availability, and suitability to show overarching drought conditions. Formal external evaluation of suitability and quality may be addressed in the future. Future products to be considered include a suite of Palmer indices as well as soil moisture and other remotely sensed products. These global products will be relatively small in number and are meant to provide a global overview of drought conditions and to allow intercomparisons of drought across the world, especially along international and regional boundaries. These high-level products are developed using some of the best quality climate information available (Peterson and Easterling 1994), provide a broad-brush look at global drought conditions, and are presented as plain text and

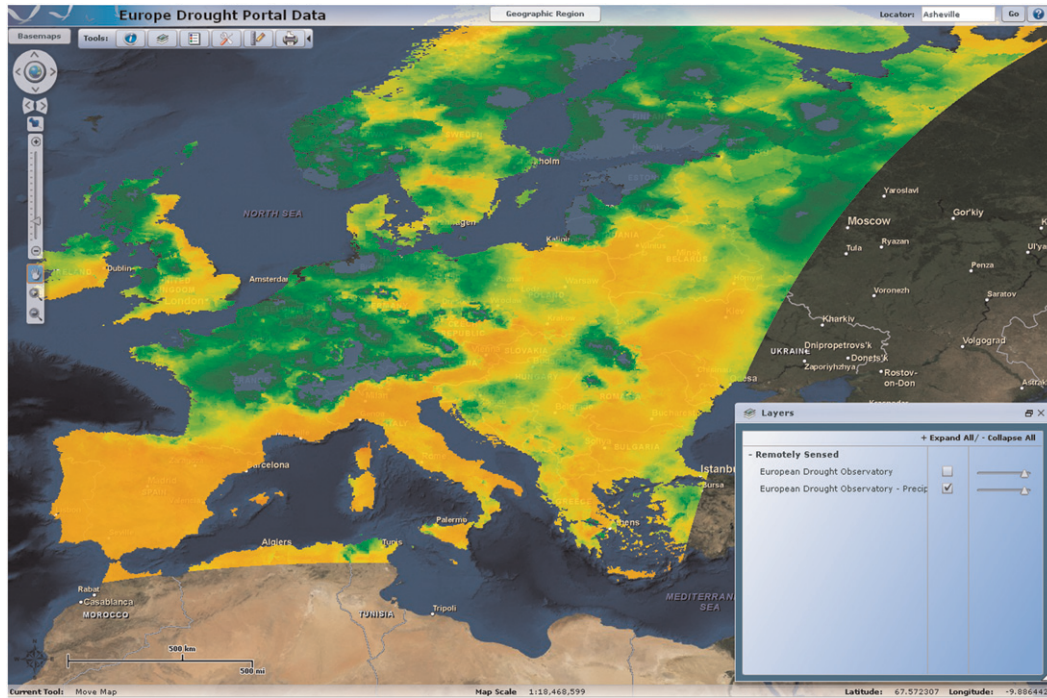


Figure 14. Example of European drought depiction provided by the European Drought Observatory, depicted on the Global Drought Monitor Portal using a hybrid base map.

static images to encourage use in limited bandwidth areas. Because they use common base periods, they are appropriate for comparing drought status between locations around the world but do not necessarily represent the severity of a drought at an individual location compared to its full period of record. To do that, one must use the third section of the GDMP described below.

The second section of the GDMP includes an interactive map and data viewer. For locations with higher bandwidth, Open Geospatial Consortium (OGC)–compliant web mapping services (WMS) are available and are the mechanism by which regions and continents provide their information to the GDMP. This allows the availability of a larger suite of tools since production and maintenance is distributed and also allows users to get more detailed local information. The user may select from a variety of base maps (satellite, streets, topography, geographic relief, and hybrid) and layers. The layers include station-based data (SPI at seven time scales from 1 to 24 months) (Figure 8); remotely sensed data (Figure 9); and drought depictions from the NADM, EDO, and ADM (Figure 10), with the capability of overlaying multiple layers (Figure 11). Through the interactive map viewer, users can zoom all the way to individual stations to get a detailed look at the drought in a specific location, including time series of drought indicator data for that station (Figure 12). Currently, North America (Figure 13), Europe (Figure 14), and Africa (Figure 15) are providing WMS services to “paint” a global drought picture (Figure 10). By leveraging common data formats and GEO interoperability

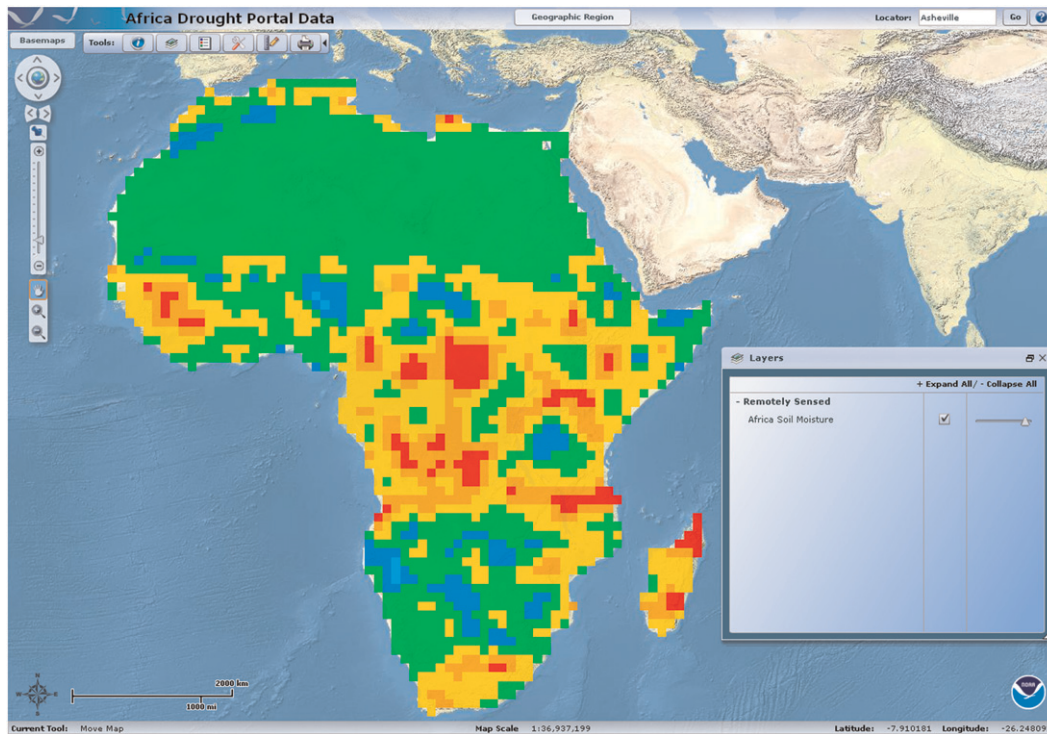


Figure 15. Example of African drought depiction provided by the African Drought Monitor, depicted on the Global Drought Monitor Portal using a topographic base map.

standards and testing, products from these three sources are available through the GDMP, as will be seen in the third section. Australia should be available soon and Argentina and Brazil are discussing available ways a South American component could be contributed. Other countries in the Middle East and Asia have expressed interest in contributing but have not yet committed to the process.

The third section of the GDMP houses a capability for users to drill down from the global to the regional scale in order to get a more robust suite of drought products and services than could be efficiently handled through a global interface. The drill-down capability allows users to pass from the global level to authorities on each continent providing regional level information for more drought information. These regional sites, such as the NADM (Figure 16) website and the European Drought Observatory (Figure 6), provide access to more tools and data than are available at the global level and further allow users to pass to individual national drought monitoring activities, such as for the United States (USDM) (Figure 17) or Spain (Figure 18), for even more specificity, since it is recognized that drought is dominantly a local phenomenon. Further drill down to states or watersheds within a country can then be provided, should the nation decide it is beneficial. By using this nested architecture, decision makers at all levels can get access to the information they need seamlessly and efficiently.

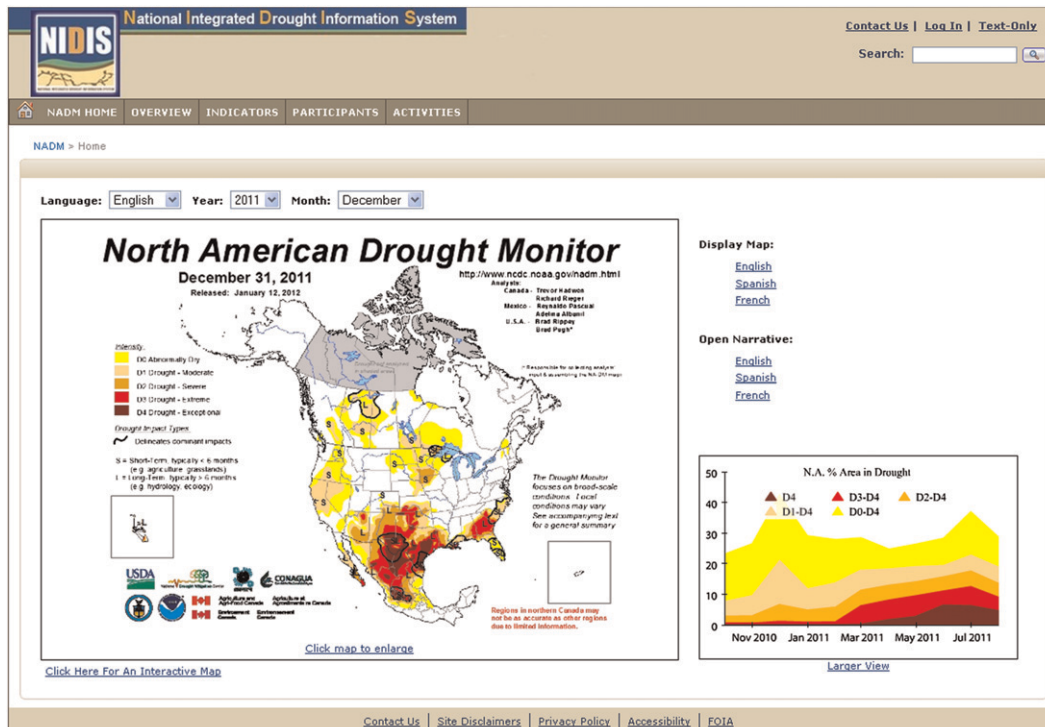
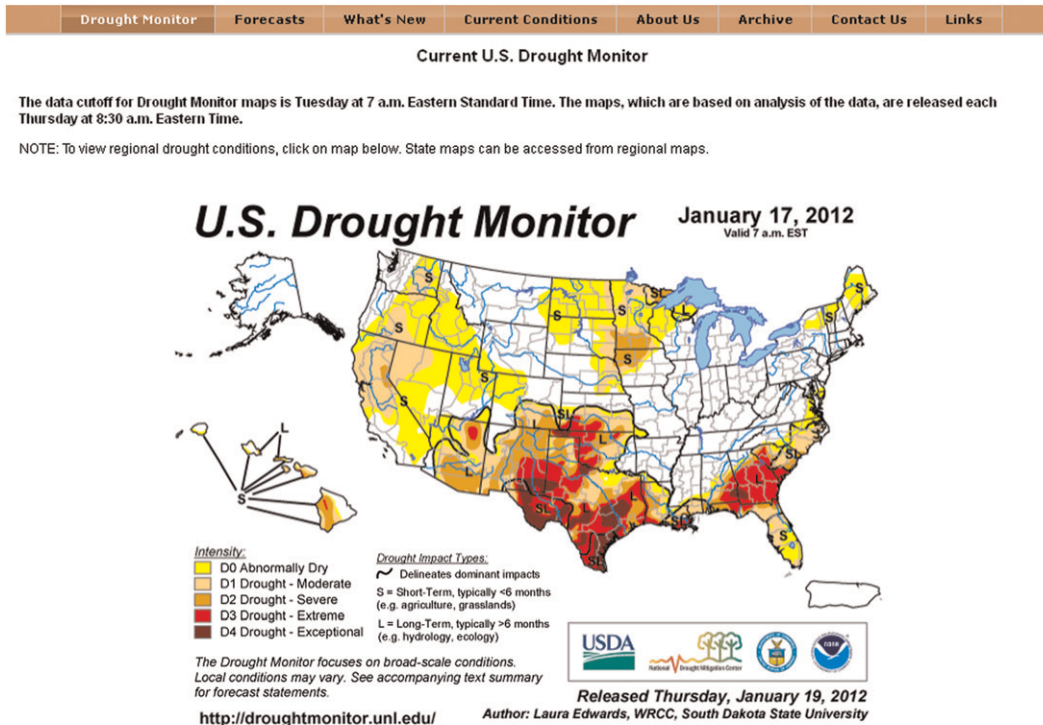


Figure 16. The North American Drought Monitor regional website housed at the NIDIS portal.

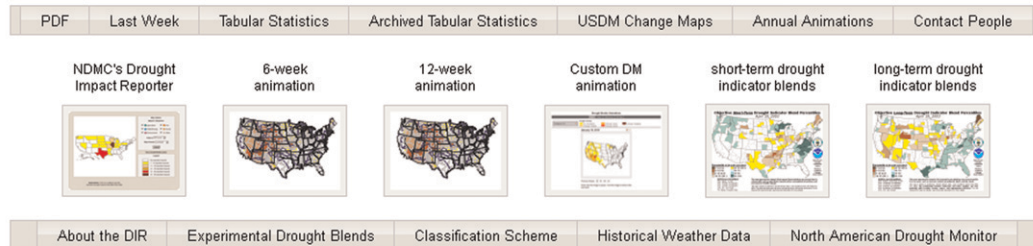
The fourth section of the GDMP is a general information section that includes details about those that participate and will also include help and details about contributing, when it is complete. The GDMP has been designed so that additional sections can be added when new components of a GDIS/GDEWS become available.

4. Summary and the future

During the past 12 months, the NIDIS and the NOAA National Climatic Data Center have been instrumental in expanding and operating the prototype Global Drought Monitor Portal while building linkages to existing international activities and programs. This effort has benefited from coordination with GEO and the WMO. The GDMP was initially established in the fall of 2010 (fiscal year 2011) with regional drought information provided by North America and Europe and for Africa by way of Princeton University. Since the initial establishment, coordination efforts have continued. Australia and South America have entered discussions on providing access to their information and, as of early 2012, Australian data have been included in a prototype server. Following approval by Australia of the way their data are provided, it will be going live on the GDMP. Further, in the spring of 2011, the GDMP was expanded to include a suite of global drought indicators identified by experts and adopted by WMO as the necessary measures to examine drought from a meteorological standpoint. The GDMP has been included in recent



UPDATE: The links have been moved into the menu bars below.



For local details and impacts, please contact your [State Climatologist](#) or [Regional Climate Center](#).

National Drought Summary -- January 17, 2012

The discussion in the Looking Ahead section is simply a description of what the official national guidance from the National Weather Service (NWS) National Centers for Environmental Prediction is depicting for current areas of dryness and drought. The NWS forecast products utilized include the HPC 5-day QPF and 5-day Mean Temperature minus the 5-day Normal of Temperature and Precipitation Probability, and the 5-day Normal of Temperature and Precipitation Probability, valid as

Figure 17. The U.S. Drought Monitor homepage is housed at the National Drought Mitigation Center.

updates to the GEO work plan. Finally, the GDMP has benefited from substantial coordination with WMO on both their Global Framework for Climate Services and the National Drought Policy efforts. The GDMP is recognized as having the potential to be a major contributor to both of these activities.

Future plans involve operational release of the Australian drought information and continued interaction with South America on their involvement. Additional coordination with appropriate parties in Asia is also expected. Further coordination

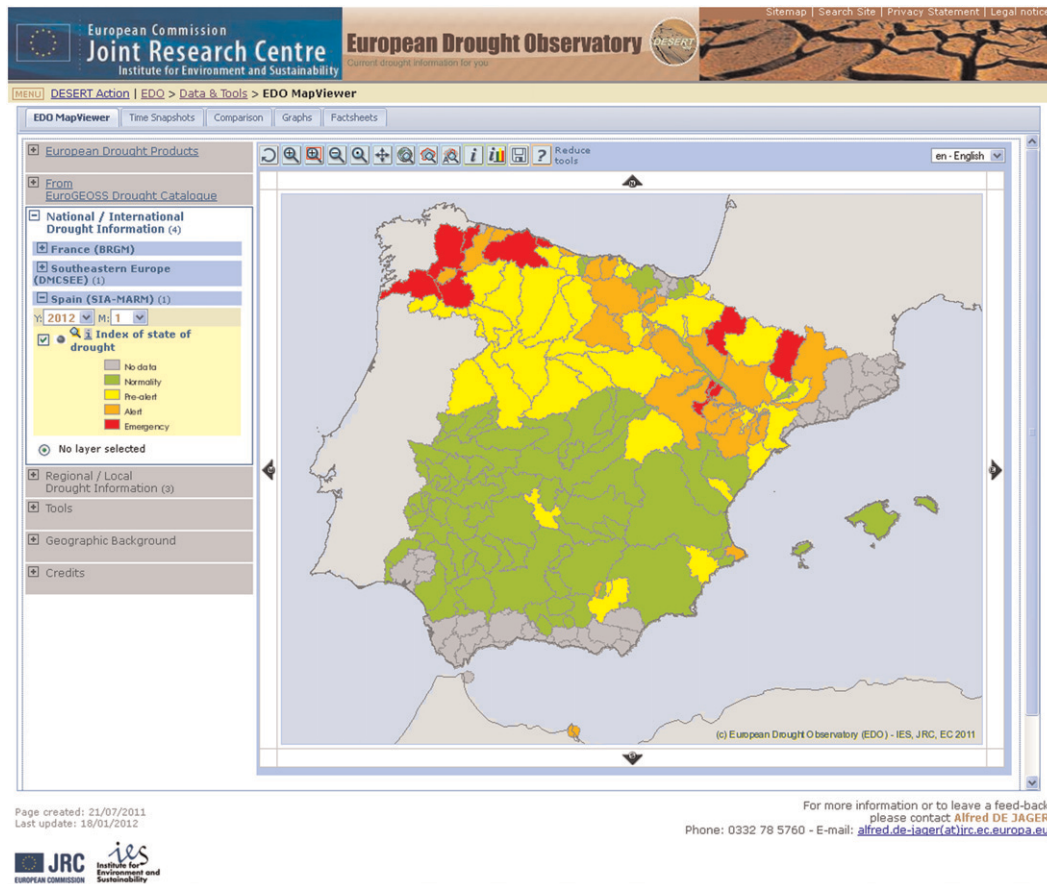


Figure 18. Example of drought conditions in Spain, provided by the Sistema Integrado de Información del Agua (SIA) within the Spanish Ministry of Rural and Marine Environment, accessed via the European Drought Observatory.

with the World Climate Research Program and WMO on leveraging the GDMP example and infrastructure to begin establishment of a GDIS is also underway as is continuing discussions with WMO on the GDMP's place in the Global Framework for Climate Services.

Limited scientific and technical resources frequently inhibit climate monitoring, sustainability, and development in some parts of the world. Mechanisms such as the UNCCD help peoples in semiarid regions to combat desertification and mitigate the effects of drought. The creation of the GDMP is a new tool that provides crucial support for drought monitoring and mitigation in semiarid regions and other parts of the world. The GDMP provides important drought information to participating nations as well as serves as an infrastructure that can be populated with drought information originating from nations in all parts of the world. It is available to all parties who have an interest and stake in drought monitoring, forecasting, impacts, mitigation, research, and education. The GDMP provides crucial support for

drought monitoring and mitigation, especially in semiarid regions, thus enhancing climate monitoring, sustainability, and development in semiarid regions and around the world.

Acknowledgments. The authors wish to thank and acknowledge all those involved in GDMP–GDIS activity. The path to this activity has been a long one stretching over the past 5 years with the last 2 seeing intensive activity and partnerships bearing fruit. While there are too many individuals to mention from our numerous interactions with WMO, GEO, and WCRP, we wish to thank all for their contributions to this activity. In particular, we would like to acknowledge Dr. M. V. K. Sivakummar and Mr. Robert Stefanski at the WMO, Mr. Will Pozzi at GEO, Dr. Roger Pulwarty at NOAA, and Dr. Donald Wilhite at the University of Nebraska at Lincoln. Without their assistance with coordination and organization, the project would not have been able to gather as many partners as it currently has. We also wish to acknowledge Dr. Siegfried Schubert for leading efforts that will improve the suite of drought prediction products available for inclusion in the project. Finally, we thank those we are directly partnering with to share information on an operational basis: Dr. Jürgen Vogt at EDO, Dr. Justin Sheffield at Princeton University, Dr. Ben Lloyd-Hughes at the University College of London, Dr. Margaret Nicholson at the Australian Bureau of Agriculture and Resource Economics, and Dr. Jaya Jayasuriya at the Australian Bureau of Meteorology. It is their willingness to coordinate with national and local partners to provide an integrated regional depiction of drought that is the basis for the success of this project.

References

- Adger, N., and Coauthors, 2007: Summary for policymakers. *Climate Change 2007: Impacts, Adaptation and Vulnerability*, M. L. Parry et al., Eds., Cambridge University Press, 7–22.
- AMS, 1997: Meteorological drought—Policy statement. *Bull. Amer. Meteor. Soc.*, **78**, 847–849.
- Barnett, T., and Coauthors, 2008: Human-induced changes in the hydrology of the western United States. *Science*, **319**, 1080–1083, doi:10.1126/science.1152538.
- Brewer, M. J., and R. R. Heim Jr., 2011a: International drought workshop series. *Bull. Amer. Meteor. Soc.*, **92**, E29–E31.
- , and —, 2011b: The Global Drought Monitor Portal. *Towards a Compendium on National Drought Policy: Proceedings of an Expert Meeting on the Preparation of a Compendium on National Drought Policy*, M. V. K. Sivakumar et al., Eds., World Meteorological Organization, 115–124.
- Brown, J. F., B. D. Wardlaw, T. Tadesse, M. J. Hayes, and B. C. Reed, 2008: The Vegetation Drought Response Index (VegDRI): A new integrated approach for monitoring drought stress in vegetation. *GIScience Remote Sens.*, **45**, 16–46, doi:10.2747/1548-1603.45.1.16.
- Cayan, D. R., T. Das, D. W. Pierce, T. P. Barnett, M. Tyree, and A. Gershunov, 2010: Future dryness in the southwest US and the hydrology of the early 21st century drought. *Proc. Natl. Acad. Sci. USA*, **107**, 21 271–21 276.
- Hadwen, T., 2012: Monitoring and assessing drought and drought impacts in Canada. *Proc. North American Drought Monitor Forum*, Cancún, Mexico, CONAGUA, 38 pp. [Available online at <http://nidis1.ncdc.noaa.gov/imageserver/NIDIS/workshops/nadm/2012/Hadwen%20-%20NADM%20Forum%202012.pdf>.]
- Hayes, M., M. Svoboda, N. Wall, and M. Widhalm, 2011: The Lincoln declaration on drought indices: Universal meteorological drought index recommended. *Bull. Amer. Meteor. Soc.*, **92**, 485–488.

- Heim, R. R., Jr., 2002: A review of twentieth-century drought indices used in the United States. *Bull. Amer. Meteor. Soc.*, **83**, 1149–1165.
- , and M. J. Brewer, 2010: The development of an international drought clearinghouse and summary of results of the April 2010 Global Drought Assessment Workshop. *Proc. Second Int. Conf. on Climate, Sustainability and Development in Semi-arid Regions*, Fortaleza, Brazil, Government of Ceará State. [Available online at <http://www.icid18.org/files/articles/683/1277920868.pdf>.]
- Lawrimore, J., R. R. Heim Jr., M. Svoboda, V. Swail, and P. J. Englehart, 2002: Beginning a new era of drought monitoring across North America. *Bull. Amer. Meteor. Soc.*, **83**, 1191–1192.
- Lobato Sánchez, R., 2012: Acciones del SMN en el Monitoreo de la Sequía—Retos y Oportunidades. *Proc. North American Drought Monitor Forum*, Cancún, Mexico, CONAGUA, 22 pp. [Available online at http://nidis1.ncdc.noaa.gov/imageserver/NIDIS/workshops/nadm/2012/Rene%20Lobato-presentacion_SMN_NADM_2012.pdf.]
- Markandya, A., 2010: The economic costs and consequences of droughts. Basque Centre for Climate Change Rep., 28 pp. [Available online at <http://www.iamz.ciheam.org/nemedca/istanbul2010/Presentations/S2-Markandya.pdf>.]
- NPIT, 2007: The National Integrated Drought Information System implementation plan: A pathway for national resilience. National Integrated Drought Information System Program Implementation Team Rep., 29 pp. [Available online at <http://www.drought.gov/media/imageserver/NIDIS/content/whatisnidis/NIDIS-IPFinal-June07.pdf>.]
- Peterson, T. C., and D. R. Easterling, 1994: Creation of homogeneous composite climatological reference series. *Int. J. Climatol.*, **14**, 671–679.
- Rossi, S., and S. Niemeyer, 2010: Monitoring droughts at the European scale: The European Drought Observatory. *Proc. Water Scarcity & Droughts Stakeholder Meeting*, Brussels, Belgium, JRC, 24 pp. [Available online at http://ec.europa.eu/environment/water/quantity/pdf/stakeholders/JRC_European_Drought_Observatory.pdf.]
- Sheffield, J., E. F. Wood, D. P. Lettenmaier, and A. Lipponen, 2008: Experimental drought monitoring for Africa. *GEWEX News*, Vol. 18 (3), International GEWEX Project Office, Silver Spring, MD, 4–6.
- Sivakumar, M. V. K., 2009: Early warning systems for drought: Past and present. *Proc. WMO Inter-Regional Workshop on Indices and Early Warning Systems for Drought*, Lincoln, Nebraska, WMO, 42 pp. [Available online at <http://nidis1.ncdc.noaa.gov/imageserver/NIDIS/workshops/nadm/2012/S22-Sivakumar.pdf>.]
- , R. P. Motha, D. A. Wilhite, and D. A. Wood, Eds., 2011a: Agricultural drought indices: Proceedings of an expert meeting, Murcia, Spain, 2–4 June 2010. World Meteorological Organization Tech. Document AGM-11, WMO/TD-1572, WAOB-2011, 220 pp.
- , —, —, and J. J. Qu, Eds., 2011b: Towards a compendium on national drought policy: Proceedings of an Expert Meeting on the Preparation of a Compendium on National Drought Policy. World Meteorological Organization Rep. AGM-12, WAOB-2011, 135 pp.
- Stefanski, R., 2011: Hydrological drought: Outcome of previous workshops. *Proc. Expert Meeting on Hydrological Drought Indices*, Geneva, Switzerland, WMO/UNISDR, 49 pp. [Available online at <http://www.wamis.org/agm/meetings/hdi11/S2-Stefanski.pdf>.]
- Svoboda, M., and Coauthors, 2002: The Drought Monitor. *Bull. Amer. Meteor. Soc.*, **83**, 1181–1190.
- Vogt, J., 2010: Towards a European Drought Observatory (EDO). *Proc. JRC Information Exchange Day*, Madrid, Spain, JRC, 18 pp. [Available online at http://ec.europa.eu/dgs/jrc/downloads/20100602_infoday_madrid_vogt.pdf.]
- WCRP, 2011: Project report: WCRP Workshop on Drought Predictability and Prediction in a Changing Climate. World Climate Research Program Informal Rep. 21/2011, 34 pp.
- Wilhite, D. A., 2002: Combating drought through preparedness. *Nat. Resour. Forum*, **26**, 275–285.
- , 2005: *Drought and Water Crises: Science, Technology, and Management Issues*. Taylor & Francis Group, 432 pp.

- , and M. Buchanan-Smith, 2005: Drought as hazard: Understanding the natural and social context. *Drought and Water Crises: Science, Technology, and Management Issues*, D. A. Wilhite, Ed., Taylor & Francis Group, 3–29.
- , M. K. V. Shivakumar, and D. A. Wood, Eds., 2000: *Early Warning Systems for Drought Preparedness and Drought Management: Proceedings*. World Meteorological Organization, 185 pp.
- , M. J. Hayes, and C. L. Knutson, 2005: Drought preparedness planning: Building institutional capacity. *Drought and Water Crises: Science, Technology, and Management Issues*, D. A. Wilhite, Ed., Taylor & Francis Group, 93–135.
- World Meteorological Organization (WMO), 1992: International meteorological vocabulary. 2nd ed. World Meteorological Organization Rep. 182, 784 pp.
- Zwiers, F. W., and Coauthors, 2011: Community paper on climate extremes: Challenges in estimating and understanding recent changes in the frequency and intensity of extreme climate and weather events. *Proc. Open Science Conf.*, Denver, CO, World Climate Research Programme, 45 pp. [Available online at <http://www.wcrp-climate.org/conference2011/documents/Extremes.pdf>.]

Earth Interactions is published jointly by the American Meteorological Society, the American Geophysical Union, and the Association of American Geographers. Permission to use figures, tables, and *brief* excerpts from this journal in scientific and educational works is hereby granted provided that the source is acknowledged. Any use of material in this journal that is determined to be “fair use” under Section 107 or that satisfies the conditions specified in Section 108 of the U.S. Copyright Law (17 USC, as revised by P.L. 94-553) does not require the publishers’ permission. For permission for any other form of copying, contact one of the copublishing societies.
